

Development of a Low-Cost and Portable Device Controller for Point-of-Care Medical Diagnostics

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Abstract— The field of centrifugal microfluidics aims to miniaturize common biochemical assays onto specialized discs (CDs). By the exploitation of the centrifugal force, centrifugal microfluidics CDs do not require the syringe pumps that stationary microfluidic platforms require. This paper describes the development of a low-cost and portable controller device that is capable of performing centrifugal microfluidics at the point-of-care (POC). Overall, this system aims to be low in cost, fast, and modular.

In this study, the Spin-Stand device controller is the final product of three stages of development: design, virtual simulation and implementation. At the core of the system, the controller is designed to adjust the disc rotational speed for performing several operations by Pulse Width Modulation (PWM) through PIC (Programmable Interface Controller).

Keywords— Lab-On-Disc, Point-Of-Care, PIC microcontroller, Portable Device, Spin-Stand Device, Microfluidic Disc.

I. INTRODUCTION

Microfluidics aims to miniaturize the diagnostic power of a complete laboratory to create portable and disposable diagnostic devices. These tools are being developed as micro total analysis systems (μ TAS) where several steps involved in sample preparation and disease detection are integrated onto a single device [1].

Such devices would bring diagnostics to the point-of-care where the treatment is administered [2]. Ideally microfluidic devices would be low in cost, operate automatically, and have low power requirements so that they can be used in low-infrastructure settings. Therefore, there is an obvious and urgent need to develop such a technology.

Centrifugal microfluidics, or microfluidic CDs, is a unique approach to the field of microfluidics where fluids are manipulated within specialized CDs by rotation. By exploiting the centrifugal

force, liquids are moved to the outer rim of the disc, eliminating the need for bulky and complex syringe pumps that stationary microfluidic chips require. In addition, in conventional stationary microfluidic chips experiments are accomplished by tedious manual intervention and expensive interconnects, creating neither a platform that is neither automated nor easy to use [3].

Centrifugal microfluidic discs emerged the 1960's in an effort to automate and perform parallel biochemical reactions on specialized fluidic discs. In the past decade the field of centrifugal microfluidics has been heavily revisited by several groups internationally (Dr. Marc Madou, USA; Dr. Jen Ducree, Ireland; Dr. Cho, Korea) [4,5]. While these groups have advanced the platform significantly, a significant problem remains: while the disc has always been portable, the supporting hardware (i.e. spin-stand, optical visualization equipment) has not been. The problem has arisen where this microfluidic discs are "chips in a lab" instead of being a "labs on a chip". This paper presents a low-cost portable device controller for point-of-care medical diagnostic applications.

II. BACKGROUND

In microfluidic discs, the rotational speed should be determined from derived fluid mechanics equations to move liquid from one point to another in a microchannel. The most basic and common form of valving on the microfluidic CD platform is capillary valving. This type of valving requires no moving mechanical parts, rather is based on holding the fluid back due to the capillary pressure generated when a small volume of liquid is forced through a constriction (i.e., a microchannel) [6]. Liquid will hold at that microchannel as long as the capillary pressure is not broken, and can be broken by applying an external force to the liquid. In centrifugal microfluidic discs, this force is the centrifugal force and liquid will break into a microchannel once the applied centrifugal force is larger than that of the capillary pressure holding the liquid back [7,8].

One application for a Spin-Stand device is for the separation of plasma from whole blood, a sample preparation step common to many biochemical diagnostic assays [9,10,11]. This will be discussed

below. The system can control the lab on a disc automatically without the need for an operator. The disc spin stand has been designed in an international standard size of 12 cm disc.

There are several variables that must be considered when designing a controller spin-stand that performs centrifugal microfluidics: motor tolerance in rotational speed, effects of vibrational noise on the fluidics, motor acceleration and deceleration rates, motor controlling mechanisms, and motor reaction time.

III. METHODS & MATERIALS

The development of a portable disc spin-stand controller system geared microfluidic disc applications included: designing of electronic circuits, choosing suitable mechanical and electrical components, writing source codes in Micro Code studio software, simulating the circuit design by Proteus software, actuating the control motor by a microcontroller, and fabricating a suitable PCB board.

A. Design

The developed system has two main parts: a specialized spin-stand and a controller unit. The system is equipped with a lens that connects to a camera. The specialized spin-stand is made of Teflon chassis which includes several parts inside: a BLDC servo-motor for spinning microfluidic discs, a fan for cooling, supporting electronic connectors to integrate electronics, and a COM port that connects to the control unit.

The controller unit consists of a keypad to give the user an interface to apply appropriate rotational speeds to the microfluidics discs, an Liquid Crystal Display (LCD) 16 Character x 2 Line that displays the rotational speed, a switch to change rotational direction (clockwise, counter clockwise), and a COM port that communicates with the spin-stand. Also within the unit is a PIC 16F877a microcontroller that controls the motor. The controller is designed to adjust the disc rotational speed for performing several operations by Pulse Width Modulation (PWM).

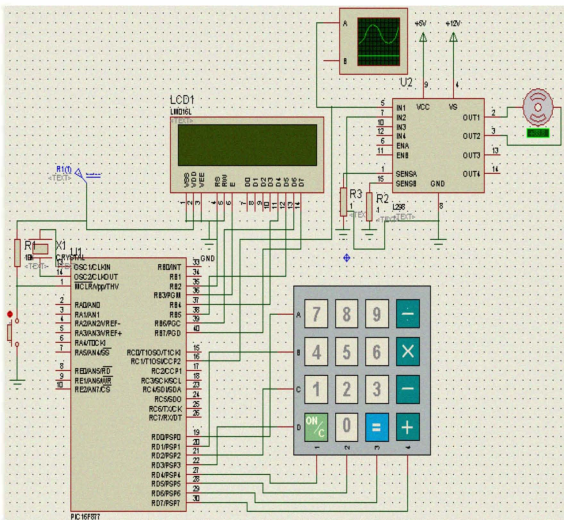


Figure 1. Simulated the control circuit by Proteus Software

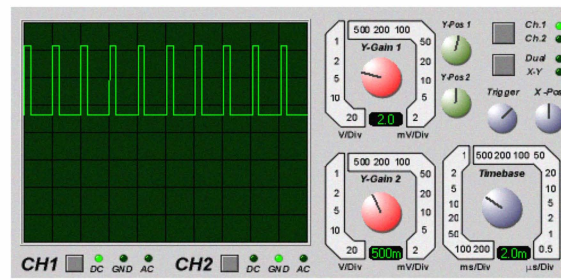


Figure 2. Output of oscilloscope indicates pulse width modulation (PWM)

B. Simulation

Circuit simulation is a technique of predicting the behaviour of a real circuit by a computer program. It replaces real components with idealized electrical models. In this study, the control circuit is simulated by Proteus software. Figure 1 illustrates schematic models which consist of an LCD, a PIC 16F877a microcontroller, a driver L298, a keypad 4 x 4, a motor, an oscilloscope, and some supporting elements for driving components.

This system can be controlled to change to the desired revolution per minute (rpm) by pressing the each button of the keypad. Each button declares each step of experiments. Figure 2 shows the pulse width modulation (PWM) which is related to each intended speed for controlling the motor. The speed of the motor displays by the LCD.

C. Implementation

The electronic components have been connected to the printed circuit board (PCB) that embedded in a plastic box with dimensions of 16_{cm} x 11_{cm} x 5_{cm}. Choosing appropriate components made unique design for commercial purposes.

Device maintenance is significant factor for instruments. Separating each component from main board is one of the advantages in this device. It applies by using communication sockets between interface wires and components such as LCD and Keypad. Therefore this benefit allows to users for changing the components in necessary time easily.

Control circuit is connected to BLDC servomotor (No. 2250S024BX4 SC, Faulhaber Series Brushless DC Servomotor) by using COM port that in fact, PWM is sent to motor through this port. Inside of main board have three input voltage, but device has only one input voltage that it produces another required voltages by employing voltage regulators. Another advantage is that device components have been calibrated separately. Not only users can adjust the device by an output port that it is considered on main board, but also they can connect it to oscilloscope for tuning the device (Figure 3).

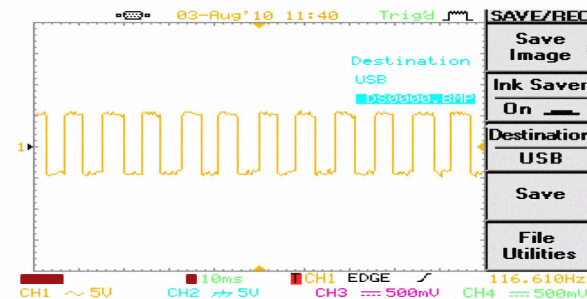


Figure 3. Output of real oscilloscope that indicates PWM



Figure 4. Spin-Stand controlling Device, BIOMEMS Lab, University of Malaya.

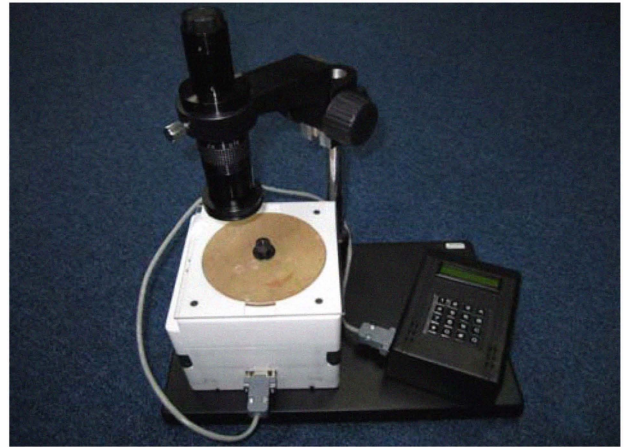


Figure 5. Spin-Stand Device, BIOMEMS Lab, University of Malaya.

Apart from previous advantages, the device is programmable. Basically user can change all definitions of the keypad buttons. Each experiment has specific speeds and incubation times for their each steps, therefore the device is designed so that can be flexible for various assays that programming port is embedded on the main board.

The system is equipped with spinning direction switch that if LCD is in front of user, it can be touched in left side of the box as shown in Figure 4.

IV. RESULTS AND DISCUSSION

The complete setup of the spin-stand device is as shown in Figure 5. The portable spin-stand controller has been tested on an application of plasma separation. The plasma separation disc has been designed and fabricated on Polymethyl methacrylate (PMMA) disc. This design was adapted from reference [9].

As shown in Figure 6, a blood sample of 100 μ Liter has been injected into chamber 1. The controller has been assigned to 3600 rpm clockwise (C.W.) for 120 seconds and then the motor direction was changed to counter clock wise (C.C.W.) for 20s at 2400 rpm. The spin-stand device can be stopped after passing these steps. All sequences have been specified as table 1. The separation of plasma can be occurring at several speed ranges. It is obviously its time and rpm will be specified by having another burst frequencies of each valve in the Lab-On-Disc.

At the end of experiment, the red blood cells (RBCs) will be accumulated at chamber 2, while the plasma is at chamber 3. This structure of extracting plasma is designed to achieved plasma of 50 μ Liter will be extracted in chamber 3. After each experiment, the results will be observed by using the Microscope.

The blood separation part can help to extract the plasma automatically and be used in diverse assays such as ELISA, DNA Hybridization, etc.

This device is beneficial for attending clinician especially in resource poor settings to make the best clinical management decision. In fact, the field of microfluidics aims to miniaturize laboratory processes to create portable diagnostic devices.

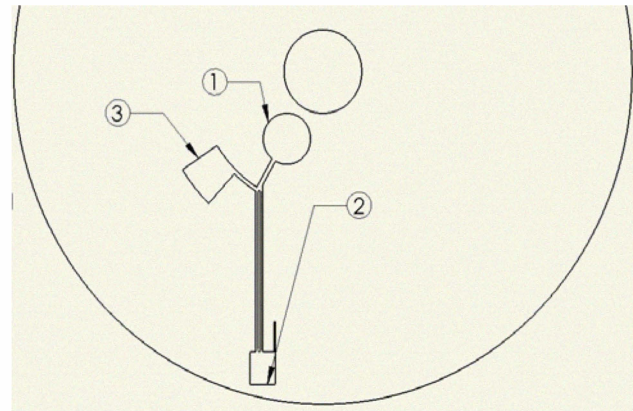


Figure 6. Blood Separation Disc, designed in BIOMEMS Lab, University of Malaya.

One of advantages of disc system is reduction of the required electrical power. The power consumption decreases with reduction in the size and weight of system and the materials used. The disc spin stand system has the advantage of being locally fabricated, with an automatic disc controller, and is portable and low-cost. It can be a local Malaysian product since the design has been developed locally according to the requirements and specifications that function for disc spin stand system. Other benefits of spin base device are as follows:

The benefits of this device are utilization of inexpensive components, easy to operate, require user input and easy to use in a wide variety of climate conditions.

Beside declared advantages, this device has easy portability. As a matter of fact it can work by battery, so it can be portable and has minimal power requirements for accomplishing each biomedical assay because of unique design.

Moreover, it is adaptable for many other medical laboratory diagnostic applications.

Table1. Sequences of extracting plasma

No. of chambers	Description of chambers	Suggested Time(s)	Volume (μLiter)	Suggested Rotation speed (rpm)
1	Whole blood (sample)	120	100	3600 C.W.
2	Storage Sedimentation (RBCs)	20	45	2400 C.C.W.
3	Plasma	0	50	0

V. CONCLUSIONS

This report successfully demonstrated a spin-stand controller that is low-cost, portable, and optimized for use at the point-of-care for plasma separation. Because of the programmability of the proposed device, unique spin-profiles can be programmed by the user to perform a particular assay (e.g., ELISA for any infectious diseases and PCR) automatically. Since the system uses off-the-shelf, the device as a whole is suitable for commercialization. It is envisioned that the proposed device can be used for later clinical testing to determine both the performance and efficacy of the new technology. After such testing, the device would then be used by health care professionals in clinical settings (a traditional doctor's offices or in a remote setting with low-infrastructure) to perform centrifugal microfluidics.

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